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DEPENDENCE OF CHARGE COLLECTION DISTRIBUTIONS AND DOSE ON THE GAS TYPE FILLING THE IONIZATION CHAMBER FOR A p(66)Be(49) CLINICAL NEUTRON BEAM.

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ABSTRACT

Measurements of central axis depth charge distributions (CADCD) in a p(66)Be(49) clinical neutron beam using A-150 TE plastic ionization chambers (IC) have shown that these distributions are dependent on the gas type filling the ICs. IC volumes from 0.1 to 8cm^3 and nine different gases were investigated. Off axis ratios and build-up measurements do not seem to be as sensitive to gas type.

The gas dosimetry constants given in the AAPM Protocol for Neutron Beam Dosimetry for air and methane based TE gases were tested for consistency in water and in TE solution filled phantoms at depths of 10 cm, when used in conjunction with an IC having 5 mm thick walls of A-150.

KEY WORDS: Neutron, dosimetry, ionometry, gases, CADD, absorbed dose.

INTRODUCTION

A-150 TE plastic[1] ICs were filled with various gases and then irradiated in a water filled phantom by a p(66)Be(49) clinical neutron beam to see if the gas type affected the measurements of central axis depth charge distributions (CADCD) and off axis ratios (OAR). Absolute dose determinations were made in both TE solution[2] and water filled phantoms. Measurements of charge collection in the build-up (BU) region were made in air.

The most striking result is that CADCDs cannot always be related to central axis depth dose (CADD) distributions via a multiplicative constant as it is the current practice.[3,4] Assuming that one of the CADCD obtained with an IC filled with A-150 plastic equivalent gas[5] multiplied by a constant gives a CADD distribution close to the true total absorbed dose distribution, then the non-hydrogenous gases would need depth dependent variables to convert collected charge to absorbed dose in, say, muscle tissue.

This paper deals with charge collection by different ICs filled with different gases due to total absorbed dose in the gas, ie., photon plus neutron doses. In the DISCUSSION and CONCLUSIONS, the implications of these measurements on neutron dosimetry are presented.

EXPERIMENTAL SET-UP AND PROCEDURES

The electronics for charge collection from the ICs, automatic compensation for gas temperature and pressure, remotely controlled positioner for the ICs in the phantoms and a description of the beam irradiation facility have been described previously.[6-9] Here the neutron beam had a cross-section[10] of 20x20 cm^2 at 10 cm deep in a water-filled phantom whose thin entrance window was located at SSD = 180 cm.

All the ICs were made of A-150 TE-plastic and operated at +600 V, except for the 0.1 cm^3 IC which was operated at +300 V. The ICs used were, (1) parallel plate, 1 mm wide gap,[11] (2) 0.1 cm^3, thimble,[12] (3) 0.5 cm^3, thimble,[13,14] (4) 1 cm^3, spherical,[14,15] and (5) 8 cm^3, spherical.[16]

The gases used are listed in Table I. They were obtained from Matheson Gas Products Co., Joliet, IL 60435. The purities listed are those stated by the seller. Not all gases were used in all the ICs. To ascertain that the gases were at room temperature after the adiabatic decompression from the storage bottles, the gases passed through a 7.6 m long, 6 mm diameter thin wall copper tube before entering the ICs.[17] During gas changes, these lines were flushed independently of the ICs to avoid stressing the IC walls. The gas flow was kept at a level just above the threshhold for bubble production in alcohol. Normally, a gas change required

about one hour of gas preflow at 2-5 cm^3/min, with the IC in the neutron beam to achieve stable operation.

To set the zero for the coordinates of the central axis, stainless steel gauges machined specially for each IC were used. They positioned the center of the ICs at 10 cm from the outside of the 0.3 cm thick entrance window of the phantom.

In all data taking runs, charge collection at three points, be they depth, off axis distances at constant depth, or BU thicknesses, were measured repeatedly to ascertain system stability and to be able to estimate the uncertainty associated with the individual measurements. For example, in the CADCD measurements, these points were at depths of 2, 10, and 32 cm. Also, most measurements were repeated several times over a period of four months with a precision of $\pm$0.3%. The combined uncertainties in measured quantities from charge, position, temperature and pressure measurements are estimated to add $\pm$0.2%, in quadrature. The ratios are estimated to have uncertainties ranging from $\pm$0.5 to $\pm$0.6% (one standard deviation).

For general interest, Table I also gives the charges collected by the 1 cm^3 IC, at a depth of 10 cm, in the water filled phantom, when filled with different gases relative to the charge collected using A-150 plastic equivalent gas.[5]

RESULTS AND DISCUSSION

CADCD Measurements.

The CADCD results are presented graphically in Figs. 1-7, where the distributions and ratios of distributions are normalized to unity at a depth of 10 cm.

Only the 0.1 cm^3 and the 1.0 cm^3 ICs were extensively studied. Since the differences in distributions are small (Fig. 1), the results are also shown as ratios of charge collection measurements for the various gases to similar measurements using A-150 gas (Figs. 2-7). These ratios are normalized to unity at a depth of 10 cm.

In order to interpolate unbiasedly between measured points, a quadratic polynomial of the form $\ln[R(z)] = az^2 + bz + c$ was fitted through four points at a time such that there were two data points at either side of each interpolation region. This interpolation method[18] was chosen instead of an analytical function fit used in an earlier report[10] to avoid prejudging the form of the CADCD curves. As it would be expected, the fits to the data points are good (Fig. 1). However, this method introduces discontinuities every time the set of four points used to define the polynomial is changed by "sliding" along the depth dose curve. These artifacts, although barely visible on the

fitted CADCD curve (Fig. 1), tend to increase the noise when ratios are taken (Figs. 2-7). Trends in the data, however, are clearly represented and no further smoothing was employed.

A simple inspection of Figs. 2-6 shows that if an IC filled with one type of gas is assumed to give a CADCD convertible to a CADD distribution via a multiplicative constant, then the output of the same IC with a non-hydrogeneous gas fillings would be related to the CADD distribution by a depth dependent function and not a simple constant as recommended in the AAPM Protocol for Neutron Beam Dosimetry[3] and the European Neutron Dosimetry Protocol.[4]

The presence of the 3.2% N_2 which appears in the recipes for the TE-methane[19] and A-150 gases[5] does not seem to affect significantly the apparent CADCD distributions with respect to that of pure hydrocarbon gases. That is to say, that in these two gases the thermal neutron flux does not contribute noticeably to the total charge collection via the $^{14}_{7}N(n_{th},p)\ ^{14}_{6}C$ reaction in the p(66)Be(49) neutron beam. This means that if in the future, a search is made for a non-hygroscopic hydrogenous conductive plastic for the manufacturing of ICs for fast neutron beam dosimetry in clinical situations, then the presence or absence of nitrogen may not be important for the higher energy neutron beams. Obviously, further measurements under identical irradiation conditions should be made using ICs with and without nitrogen in

the walls and filled with appropriate gases before this question may be answered properly.

At this time we do not have a quantitative explanation for the above results. However, qualitatively, two effects may contribute to the variations in the CADCDs as a function of the gas type filling the IC. One is that the charge particle distribution density inside the gas of the IC changes depending on the gas nature, i.e., hydrogenous versus non-hydrogenous, thus affecting the "effective point" of measurement. This effect would be most visible at shallow depths where most slow neutrons are inelastically scattered and removed from the incident beam. The second effect that may contribute to the over-response of some gases at large depths may be that as the average atomic number of the gas increases, the photoelectric cross-section increases and the photon component of the radiation field makes too large a contribution vis-a-vis the neutron contribution to the collected charge. This effect would become more important as a function of depth as the fractional photon dose increases vis-a-vis the neutron dose.[20,21]

The first point needs further clarification. The recoiling charge particles, due to the incident neutron beam in an IC, may be geographically classified accordingly to their relation to the gas volume of the IC into crossers, insiders, starters and stoppers.[22] The presence or absence of hydrogen in the gas volume

will affect these four groups differently. The crossers will be least affected and they will continue to deposit energy uniformly in the gas. Fewer high energy, longer range insiders and starters will be created in a non-hydrogenous gas, but to a first approximation the insiders and starters will still deposit energy uniformly in the gas volume. In the case of the stoppers in a non-hydrogenous gas there will be a non-uniform distribution of charge deposition. There will be many more stoppers due to the hydrogen content in the A-150 TE plastic wall near the "upstream" side of the gas than elsewhere in it. This is due to the preponderantly low energy component of the recoil charged particle spectrum.[23] This will effectively shift the "point of measurement" upstream for the non-hydrogenous gases with results dependent on where the measurements take place along the central axis.

Figure 7 shows the results of measuring the CADD distribution with the 1 cm^3 IC filled with A-150 and TE-methane gases and air, when the neutron beam was filtered, close to the Be-target, by 5.1 cm of high density (0.97 g cm^{-3}) polyethylene. Here, the approximate 2% drop in the charge collection by the air filled IC at 2 cm has disappeared. This may be attributed to the outscatter of the lower energy neutrons by the hydrogen of the polyethylene. In this case, for all practical purposes, the charge collected for all three gases may be related by simple constants.

OARs Measurements.

Off axis ratios were measured at three depths, 2, 10 and 20 cm, using the 0.1 cm^3 thimble IC, filled with either TE-methane gas or air. No significant differences in the distributions were detected. Therefore, neither tables nor graphs of the results of these measurements are given.

Charge Collection in the Build-up Region.

Using BU caps[23] and the 0.5 cm^3 thimble IC filled with either A-150 gas, TE-methane gas or air, the charge collection in the BU region was measured in air. No significant differences were noted. The thickness for 90% BU was about 4 mm of A-150 TE plastic for all gases. This point is much more reliably determined than the depth of maximum dose[24] which occurs somewhere in the range of 14-18 mm.

Absolute Dosimetry.

Absolute dosimetry was done using the 1 cm^3 spherical IC filled with either TE-methane gas or air in water and TE-solution filled phantoms. This IC has a 5 mm thick wall which reduces to about 0.2% the error caused when using the thick wall formalism[23] recommended by the AAPM Task Group 18 on neutron beam dosimetry.[3] The constants and formula recommended by the Task Group were used for both gases. The measurements were done at a depth of 10 cm. Both in water and in TE solution, the dose measured using air was

0.7% higher than the dose measured using the TE-methane gas. This result is of equal magnitude but opposite sign to that found at the Cleveland p(42)Be(21) beam during a recent dosimetry intercomparison.[25]

Using previously published scaling factors between water and TE-solution[26] the dose measured at 10 cm depth in TE solution was compared to the dose at 10 cm depth in water. The difference of 1.6% expected from calculation compares well with the measured difference of 1.0%.

DISCUSSION AND CONCLUSIONS

Clearly, the CADD distribution is independent of the measuring device. Therefore, only one of the CADCDs might be related to the CADD distribution via a multiplicative constant. At this time, and until further studies are carried out, we believe that the CADCD distribution measured with the parallel plate IC filled with A-150 gas and multiplied by a constant is most likely to give a CADD distribution closest to the actual one. This belief is based on the fact that an A-150 plastic IC filled with A-150 plastic equivalent gas forms the most homogeneous detector of all those employed. Furthermore, the 1 mm gap of the parallel IC should introduce the smallest depth dependent displacement correction factor variations. Of course, it is still to be shown that the dose conversion factor from charge collected

to absorbed dose in an A-150 IC filled with A-150 plastic equivalent gas, is indeed a constant for each initial neutron beam quality and filtration and independent of depth in phantom and/or beam cross-section which would affect, among other, the values of the stopping power ratio, the average energy necessary to create an electron-ion pair and the neutron beam attenuation by the IC wall. The results presented here are for a very penetrating p(65)Be(49) clinical neutron beam. Other neutron beam qualities may cause different relative charge collections as a function of position as the ICs are filled with different gases.

RECOMMENDATIONS

The characterization of clinical neutron beams should be carried out with ICs having as small a volume as possible to reduce errors from varying displacement corrections as the gradient of the radiation field changes.[18,27] Furthermore, a hydrogenous gas, and not air, should be used to fill this chamber. The use of simple but heavy hydrocarbon gases would increase the signal to noise ratio of the measurements and reduce the cost of the gas.

Further studies are needed to elucidate which are the actual depth dose distributions in clinical neutron beams and to understand the depth dependent factors needed to relate charge collections measurements to dose measurements when ionometry is

used for neutron beam dosimetry.

Finally, the dosimetric constants recommended by the AAPM Task Group 18 on Neutron Beam Dosimetry[3] should be reviewed.

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Table I

Some Characteristics of the Gases Used in the Measurement of CADCDs

Name	Composition (a)	Purity % (b)	Hydr. % (c)	RCC/MU % (d)
A-150	H, 10.2 O, 5.9 C, 76.8 F, 1.9 N, 3.6 Ar, 1.8	98	10.2	Reference
TE-methane	H, 10.2 N, 3.5 C, 45.6 O, 40.7	99.2	10.2	0.74
Ethylene	C_2H_4	99.5	14.4	0.98
1,3 butadiene(e)	C_4H_6	99.5	11.2	1.7
Nitrogen (extra dry)	N_2	99.9		0.61
Air	N, 75.5 O, 23.2 Ar, 1.3	"dry"	-	0.64
Oxygen (extra dry)	O_2	99.6	-	0.73
Argon	Ar	99.995	-	0.81
Xenon	Xe	99.995		2.0

Notes:

(a) Composition is percent by mass. A-150 (Ref. 5), TE-methane (Ref. 19), others (Ref. 28).

(b) Purity as stated by Matheson Gas Products. In the case of A-150 gas, all gas components had a purity of 99.5% or greater, except the propadiene (C_3H_4) which had a purity of 93% or greater.

(c) Percent hydrogen mass.

(d) Charge collected by 1.0 cc IC, at 10 cm deep, in water phantom, for 20x20 cm^2 p(66)Be(49) neutron beam when filled with the specified gas relative to the charge collected when filled with A-150 gas. Charges were corrected for gas temperature and pressure.

(e) CAUTION: 1,3-butadiene is not only flammable but it may also be carcinogenic and teratogenic.[29]

LIST OF FIGURES

Figure 1. Spherical IC, 1 cm^3. 20x20 cm^2 beam, water phantom. CADCD measurements using various gas fillings.

Figure 2. Parallel plate IC. 20x20 cm^2 neutron beam, water phantom. Ratio of CADCD measurements, using various gas fillings, to CADCD measurements using A-150 gas. All ratios are normalized to unity at a depth of 10 cm.

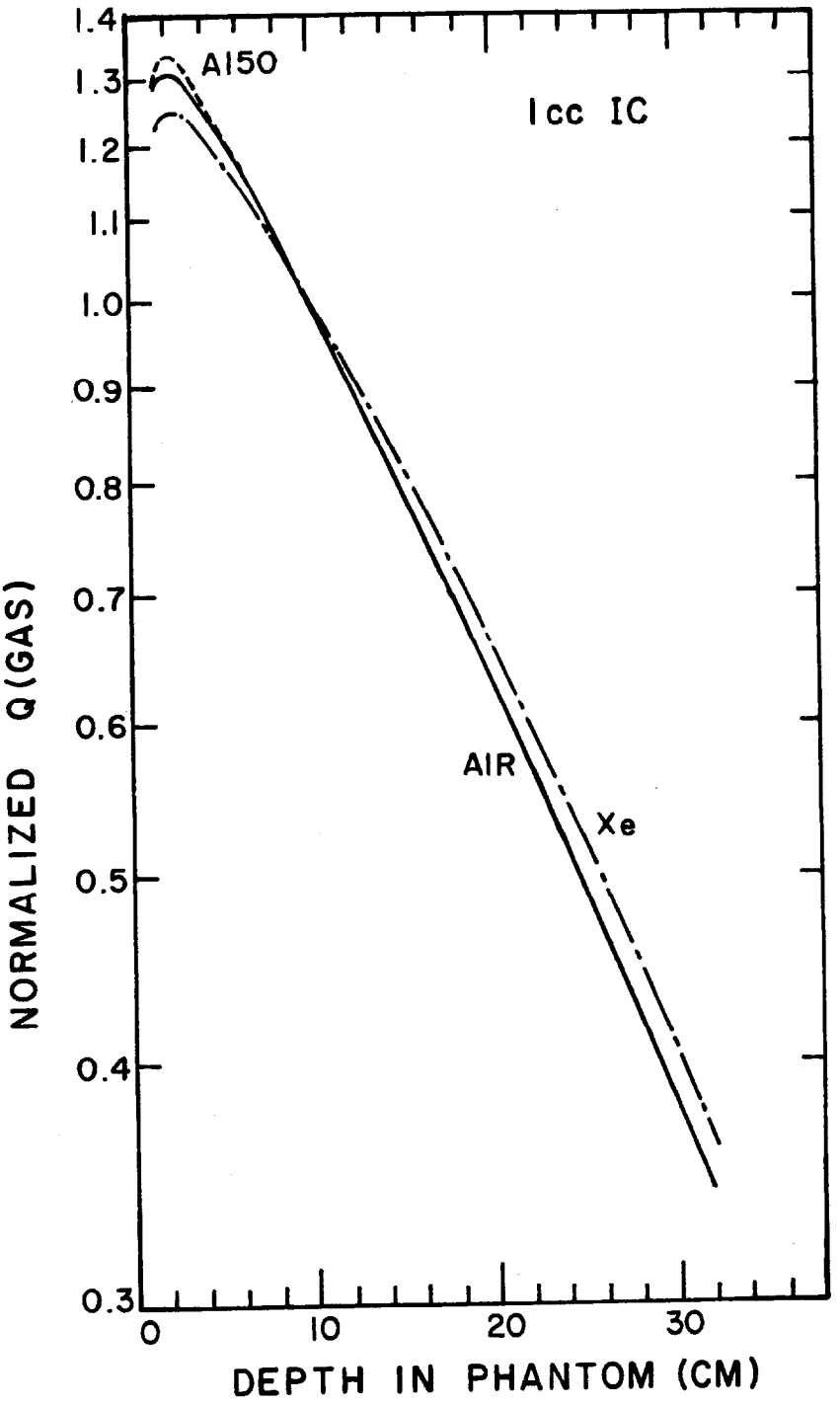
Figure 3. Thimble IC, 0.1 cm^3. 20x20 cm^2 neutron beam, water phantom. Ratio of CADCD measurements, using various gas fillings, to CADCD measurements using A-150 gas. All ratios are normalized to unity at a depth of 10 cm.

Figure 4. Thimble IC, 0.5 cm^3. 20x20 cm^2 neutron beam, water phantom. Ratio of CADCD measurements, using various gas fillings, to CADCD measurements using A-150 gas. All ratios are normalized to unity at a depth of 10 cm.

Figure 5. Spherical IC, 1 cm^3. 20x20 cm^2 neutron beam, water phantom. Ratio of CADCD measurements, using various gas fillings, to CADCD measurements using A-150 gas. All ratios are normalized to unity at a depth of 10 cm.

Figure 6. Spherical IC, 8 cm^3. 20x20 cm^2 neutron beam, water phantom. Ratio of CADCD measurements, using various gas fillings, to CADCD measurements using A-150 gas. All ratios are normalized to unity at a depth of 10 cm.

Figure 7. Spherical IC, 1 cm^3. Neutron beam filtered by 5.1 cm of high density polyethylene. 20x20 cm^2, water phantom. Ratio of CADCD measurements, using various gas fillings, to CADCD measurements using A-150 gas. All ratios are normalized to unity at a depth of 10 cm.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1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
A150
1cc IC
AIR
Xe
NORMALIZED Q(GAS)
0
10
20
30
DEPTH IN PHANTOM (CM)

Figure 1

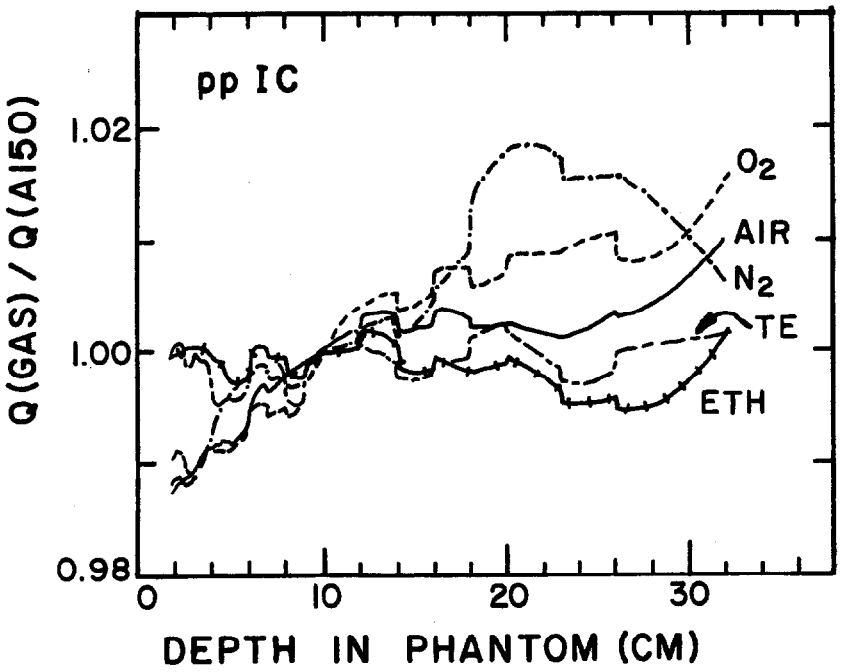
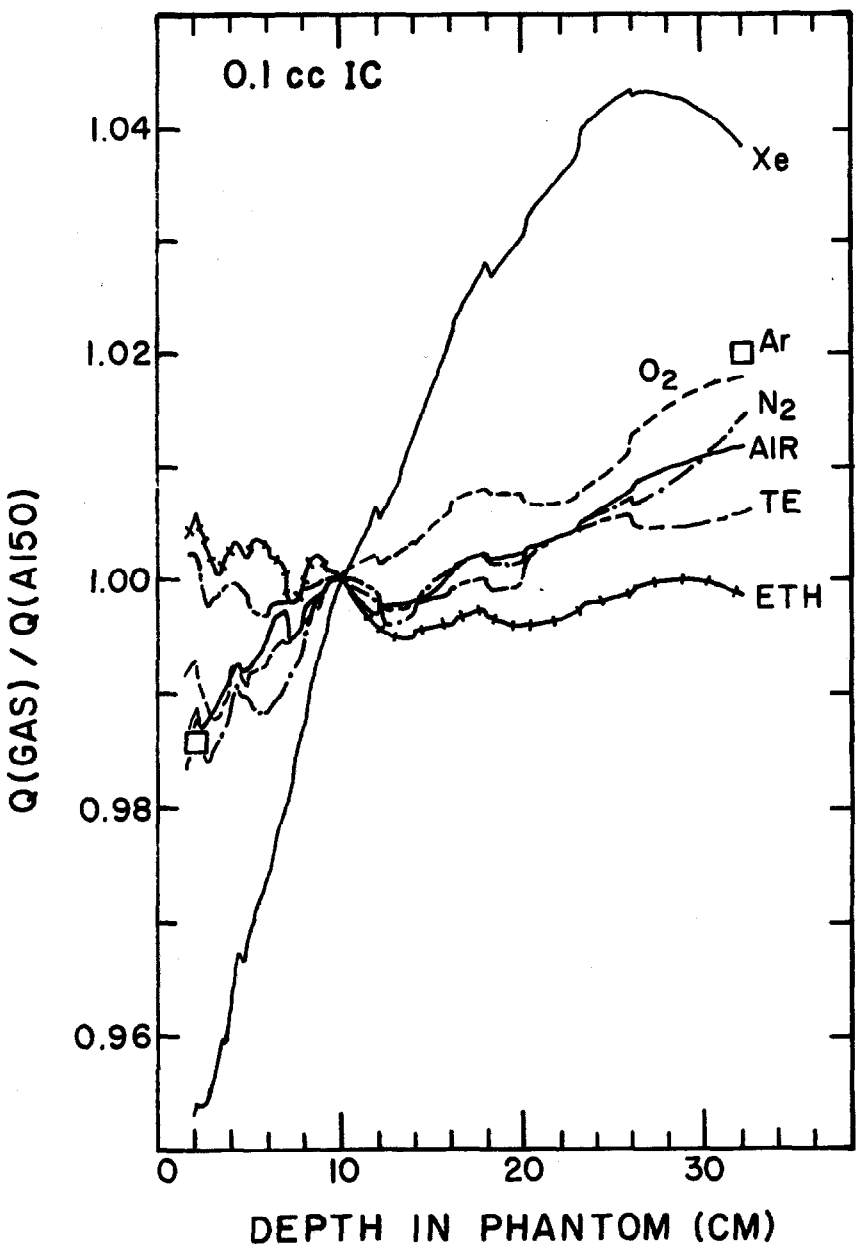

pp IC
Q(GAS) / Q(A150)
1.02
1.00
0.98
0
10
20
30
DEPTH IN PHANTOM (CM)
O2
AIR
N2
TE
ETH

Figure 2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1.04
1.02
1.00
0.98
0.96
Q(GAS) / Q(A150)
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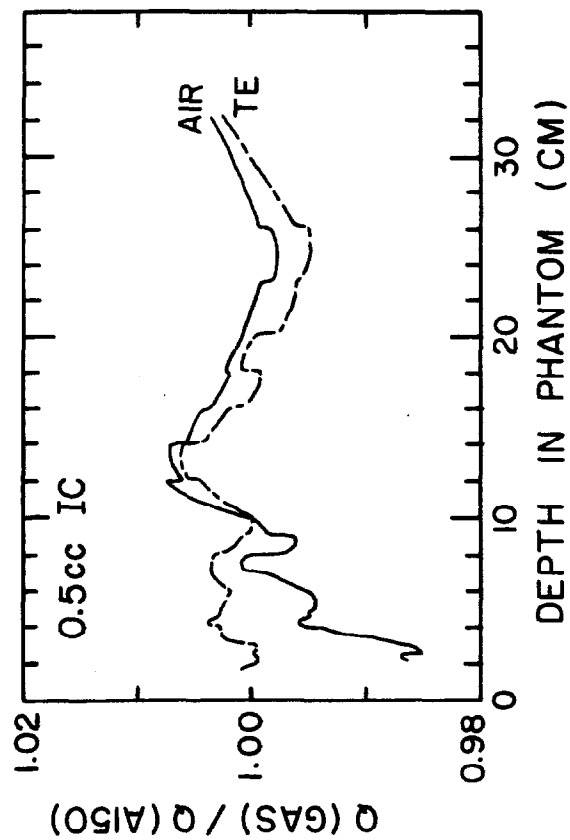
Ar
O2
N2
AIR
TE
ETH
0
10
20
30
DEPTH IN PHANTOM (CM)

Figure 3


Q (GAS) / Q (A150)
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0.98
0
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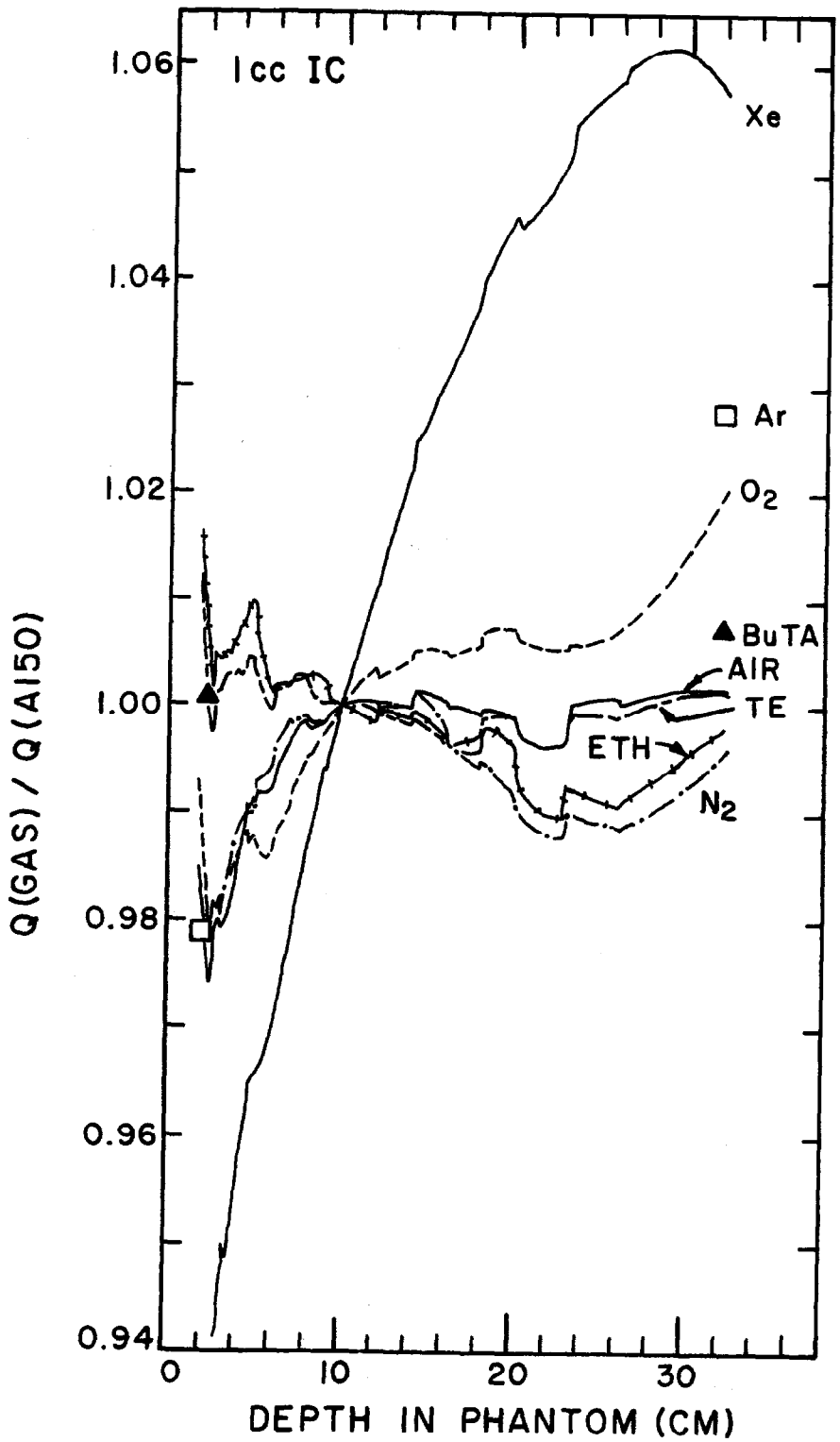
20
30
DEPTH IN PHANTOM (CM)
AIR
TE
0.5cc IC

Figure 4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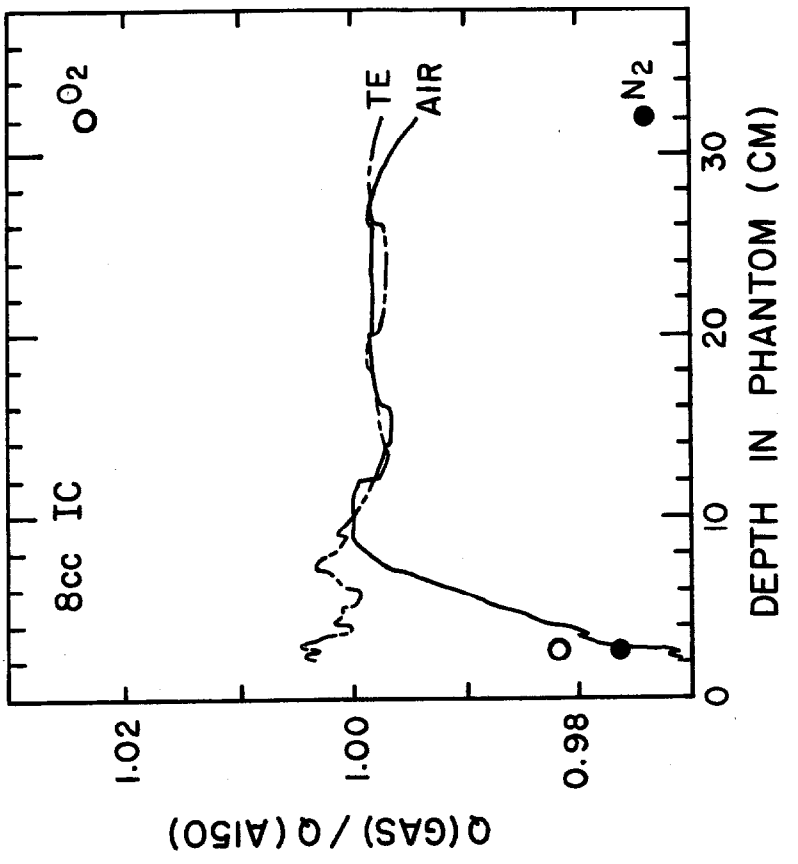
10
20
30
Q(GAS) / Q(A150)
DEPTH IN PHANTOM (CM)

Figure 5


Q (GAS) / Q (AIR)
1.02
1.00
0.98
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10
20
30
DEPTH IN PHANTOM (CM)
8cc IC
O_2
TE
AIR
N_2
O

Figure 6

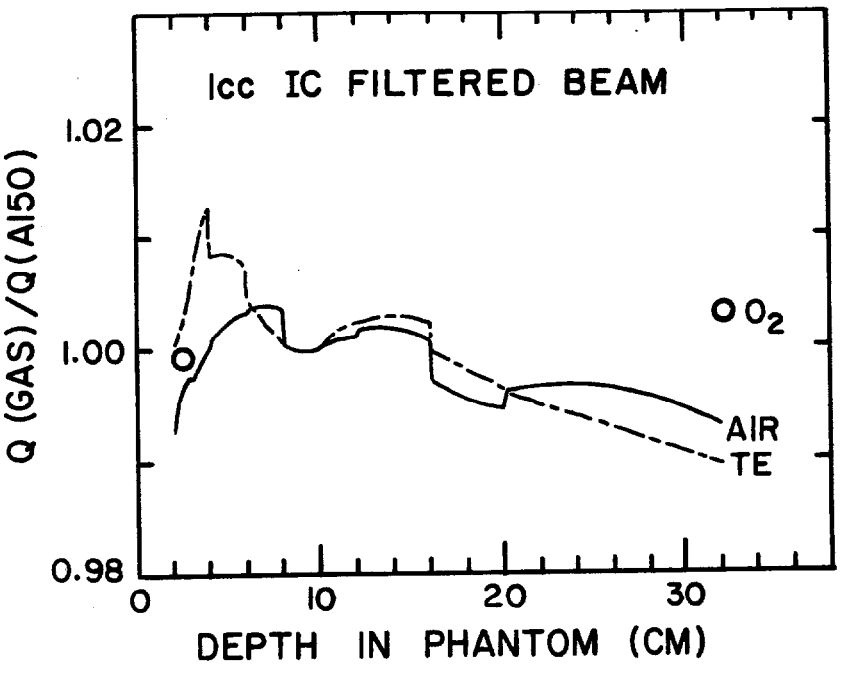
Icc IC FILTERED BEAM
1.02
1.00
0.98
Q (GAS)/Q(A150)
O O2
AIR
TE
0
10
20
30
DEPTH IN PHANTOM (CM)

Figure 7